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DESIGN AND SIMULATION OF DOUBLE WISHBONE (SLA) SUSPENSION GEOMETRY

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ABSTRACT

Widely all the incoming new era of the cars uses short and long arm dual wishbone suspension geometry system, due to its ability to perform individually without affecting the other wheel of suspension system and also to provide cornering stability. The short and long arm suspension provides the vehicle wheels to have lesser scrub radius and have negative camber gain during high speed cornering. The slight adjustments in the suspension geometry with respect to difference in upper and lower A-arm length and width between two suspension-mounting points can change the scrub radius, anti-dive and anti-squat characteristics of the vehicle. This all can result in poor vehicle ride handling characteristics and can result in decrease in life span of the tire.

KEYWORDS: Short and Long Arm Suspension Geometry, Independent Suspension System, Ride Handling Characteristics, Scrub Radius, Anti-Dive & Anti-Squat

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Original Article

1. INTRODUCTION

The major role of suspension system is to hold the tire in contact with the road and to insulate the chassis of the vehicle from the road shocks. This system is the combination of the wheel assembly with the tire connected to the chassis of the vehicle using a A-arm linkage on which a damper with coil over is fixed. The spring and damper used to absorb the energy of road shocks causes spring to oscillate the oscillations, which produced, are restricted to a level by the damper. The spring and damper combine together called as shock absorber.

1.1 Independent Suspension

The suspension setup that do not have any linkages with other wheels of the vehicle and oscillates individually during the course of suspension travel. This type of suspension oscillate individually without affecting the other suspension system. The force acting on one of the suspension assemble will not be transferred the shocks to other individual wheels of the vehicle by which all the wheels of the vehicle will remain in contact with the road.

1.2 Double Wishbone Suspension

The double wishbone suspension consist of two A-arms, where the upper arms are mechanically connected to the ball joint at one point and similarly the other end connected to the chassis of the vehicle. The upper arms connected to the upper pivot of the steering knuckle and similarly the lower arms connected to the lower pivot point of the steering knuckle.

The double wishbone suspension are most commonly preferred as front suspension geometry. There are two types of arms i. e. SLA (short long arm) unequal arms and equal arms in both cases the arms are parallel to each other but they are unequal in length. The short and long arm (SLA) geometry have parallel unequal arms with the upper arm shorter than lower arm. Such that when the body rolls it will set into negative camber and neutralize the positive camber and the changing of track width will be reduced. The negative camber is preferable because it contributes stability at sharp cornering.

However, in case of parallel equal A-arms wishbone when road shocks acts on the vehicle the tyre remains the same camber angle, which have two disadvantages:

- The outer wheel will undergo positive camber gain during the body roll.
- The track width will be changing during the bump.

2. DESIGN CONSIDERATION FOR (SLA) DUAL WISHBONE GEOMENTRY

The following number of parameters to be considered which are most vital designing the dual wishbone suspension geometry, which are

- Wheel Track
- Wheel Base
- Weight Distribution
- Wheel Size
- Centre Of Gravity
- Tire Data
- Tire Characteristics
- Length of The Wishbone
- Roll Centre
- Camber
- Castor
- Damper Angle
- Packaging Space between Damper, Wishbone and Tie-rod.

In addition, there are number of performance parameters that have tendency to change the complete vehicle dynamic characteristics with slight variation in the following attributes, which are

- Camber
- Caster
- Toe

- Motion Ratio
- Wheel Travel
- Sprung Mass
- Un Sprung Mass

2.1 Camber

It is the angle between the vertical axis of the wheels and the vertical axis of the vehicle when we view from the front or rear view. There are three types of camber,

- Zero camber
- Positive camber
- Negative camber

Zero Camber

If the top and bottom of the wheel correctly aligned to the vertical center line of the tire known as zero camber.

Positive Camber

If the top of the wheel is farther outer than the bottom that is away from the axle called the positive camber.

Negative Camber

If the bottom of the wheel is farther outer than the top called negative camber.

2.1.1 Type of Camber to Choose

Generally, camber is seen from the front view or rear view of the vehicle. Negative camber is preferred over the vehicle, which is to be designed for high-speed corners without loss of stability. This particular achieved as upper part of the tire will lean towards the frame and lower portion of the tire pushed outwards to the road surface due to which, there will be a lateral force called thrust acting initially and while cornering the tire tends to over steer easily.

However, in the positive camber the vehicle tends to lead under steer, but can contribute shorter turning radius at low speed manuring.

Camber angle can be easily adjusted in the double wishbone while camber angle fixed in the Mac Pherson strut. In addition, camber angle will be between 2.0 to 3.5 degree.

2.2 Caster

It is the angle between the pivot line and vertical line axis of the wheel i. e., pivot line is said to be the imaginary axis passing through the upper ball. There are two types of the caster

- Positive Caster.
- Negative Caster.

2.2.1 Type of Caster to Choose

The main purpose of the castor is for the steering control and better handling and for the directional stability. The positive castor angle is preferred when the vehicle need straight-line stability. The vehicle have the ability to self-

steer and align the tire straight without giving the steering input. Moreover, negative castor is not preferred because it causes the vehicle to pull which is due to the weight of the vehicle, which will causes the wheels to turn inside. Castor angle will be in the range of the 8 to 10 degree.

2.3 Toe

Toe is defined as the angle between wheel centre axis and tire pin leaning towards inwards or outwards when we see from the top vide of the vehicle. There are two types of toe

- Toe In.
- Toe Out.

2.3.1 Type of Toe to Choose

Generally toe out is preferred in the high-speed vehicle which contribute more towards the tenability factor at high speed cornering. The toe can adjusted by the steering tie-rod threads. Similarly, toe-in is preferred to achieve more straight-line stability. Toe-in geometry used in high-speed car rear tire. When the vehicle accelerated the weight shifts from front to rear where the tire move inwards and toe-in achieved. Similarly, during the course of braking the tire is pushed outward due to weight transfer from rear to front resulting in toe-out. Some point at a situation zero toe is preferred, pre fixed toe-in, or toe-out is considered as per manufacturers.

The toe should maintained at 1 to 2degree for any off-road vehicle. If there is excessive, toe the tire will undergo wear and tear and no proper, traction will attained.

2.4 Sprung Mass

In a vehicle with the suspension, the sprung mass is the portion of the vehicles total mass, which supported above the suspension. The sprung mass totally includes the body of the vehicle and the frame and the internal components and passengers.

2.5 Unsprung Mass

In a vehicle with the suspension the un-sprung mass is the mass of the suspension like wheels and other components which are directly connected to the suspension the un-sprung mass includes everything near chassis like wheel axles, wheel bearings, hubs and tires and a portion of the driveshaft's and springs and the shock absorbers.

The un-sprung mass is to be minimum as much as possible such that the vehicle acceleration will be better and handling and stability will be good.

According to the Newton's second law the mass is inversely proportional to the acceleration if the mass is more the acceleration will be less and if the mass is less the vehicle with acceleration will be increased.

2.6 Motion Ratio

Motion ratio in a suspension of the vehicle describes the amount of the shock travel with respect to the wheel travel.

If motion ratio is close to one it describes that the force will absorb by the damper, and remaining the mounting points and the frame will absorb force. The motion ratio have to set such that the damper should take the maximum force and the less force should be transferred to the frame.

2.7 Wheel Travel

Wheel travel is the distance that designed for the wheel assembly to move vertically without any bottoming out either the top or bottom of the motion. For any off road vehicle the wheel travel should be minimum of 6 inches travel.

3. CALCULATION

The following considerations are made to calculate the required parameters for suspension simulation, which are

3.1 Considerations

- Un-Sprung Mass = 34kg
- Sprung Mass on One Wheel = 49kg
- Weight on One Wheel = 49x9.8 = 480.69N
- Droop Travel = 99.5mm + 15mm = 114.5mm

Wheel Center Rate (WCR) = (Weight on One Wheel/Total Droop Travel) N/m (1)

= 480.69/114.5 x 10^{-3}

= 480.69/0.1145

= 4198.16 N/m

= 428.093 kg/m

= 287.66 lb/ft

= 287.66/12lb/inch

Spring Rate = Wheel Rate/ (Motion Ratio) ^{2} N/m (2)

= 4198.16/ $(0.7)^2$

= 8567.67 N/m

Roll Rate = (12 x Wheel Rate Center x (Track Width)^2)/2lb-ft/rad (3)

= (12 x 287.66 x (4.25)*2)/2 x 12lbft/ra

= 2597.92 lb-ft./rad

= 3522.30 N-m/rad **= 61.4754 N-m/deg**

Frequency = 1/2 x 3.14 x √(Ride Rate/Sprung Mass) Hz (4)

= (1/2 x 3.14 x root of (4198.16x2/49) Hz

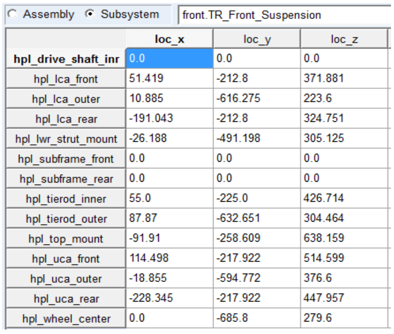
= 2.08 Hz

$$\textbf{Pro} - \textbf{dive}\ \% = \frac{(\%\ front\ braking) * (tan\emptyset_F) * l}{h} = \frac{50 * \tan(11°) * 57.5 * 0.0254}{20.3 * 0.0254} = 27.52\% \quad (5)$$

4. DESIGN AND SIMULATION

The suspension geometry was designed as per the calculated attribute by varying the every individual hard points of the suspension system. It was designed using ADAMS Car 2018 Version software using dual wishbone template. Further, the hard points were adjusted according to the required mounting point destination, wheel track and ground clearance. The dimension of the chassis were consider where the suspension wishbone is mounted on it. The number of hard points considered for the suspension system are,

The number of parameters have to be considered for the simulation of the double wishbone suspension. The simulation is carried out in number of iteration. For the particular case as initial start the parallel wheel travel simulation is carried out where the wheel travels parallel with respect to chassis. In every iteration, the results are checked to satisfy the required output. If the result produced is false the hard points of the suspension is altered to have slight change in suspension geometry. The change is been carried out in terms of altering the length of the A-arm wishbone, differentiating the length of upper and lower wishbone, change in angle of kingpin inclination, wheel centre offset, inducing angle in lower wishbone and inducing slight tilt angle in upper wishbone. The following number of parameters is consider for the suspension simulation, which are,


Assembly Subsystem front.TR_Front_Suspension

	loc_x	loc_y	loc_z
hpl_drive_shaft_inr	0.0	0.0	0.0
hpl_lca_front	51.419	-212.8	371.881
hpl_lca_outer	10.885	-616.275	223.6
hpl_lca_rear	-191.043	-212.8	324.751
hpl_lwr_strut_mount	-26.188	-491.198	305.125
hpl_subframe_front	0.0	0.0	0.0
hpl_subframe_rear	0.0	0.0	0.0
hpl_tierod_inner	55.0	-225.0	426.714
hpl_tierod_outer	87.87	-632.651	304.464
hpl_top_mount	-91.91	-258.609	638.159
hpl_uca_front	114.498	-217.922	514.599
hpl_uca_outer	-18.855	-594.772	376.6
hpl_uca_rear	-228.345	-217.922	447.957
hpl_wheel_center	0.0	-685.8	279.6

Figure 1: Suspension Hard Points Considered.

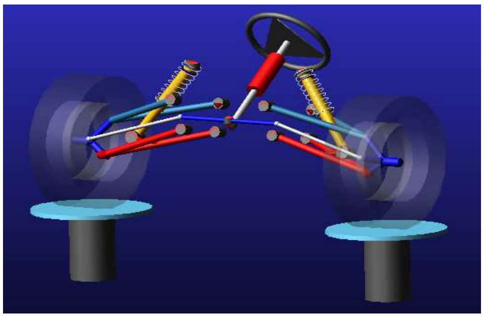


Figure 2: Suspension Design as Per Hard points in ADAMS.

Table 1: Suspension Parameter Consideration

Parameters	Front
Wheel Travel	7”
Camber Gain in Roll	-2.3º
Caster	10º
Damper Mounting Angle	65º
Sprung Mass(kg)	76.12
Unsprung Mass(kg)	26
Natural Frequency(Hz)	2.08

Stroke at 0.3m/s (mm)	52.8
Centre of Gravity(height)	24.5”
Ground Clearance	13”
Motion Ratio	0.7
Roll Centre Height	6.5”
Scrub Radius (mm)	14

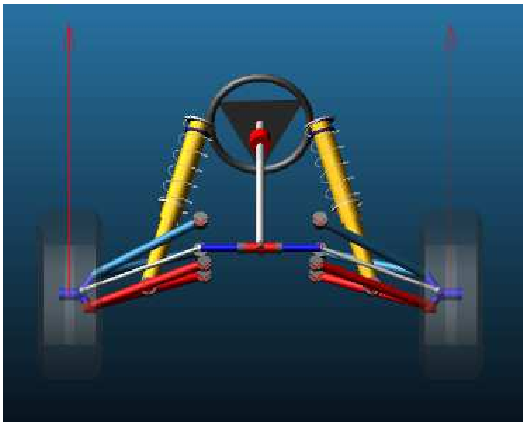


Figure 3: Suspension Travel at Ditch.

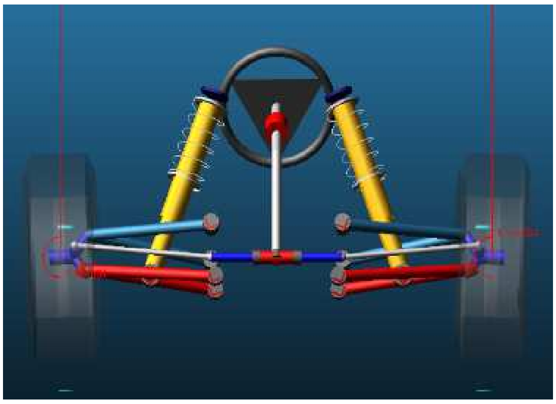


Figure 4: Suspension Travel at Bump.

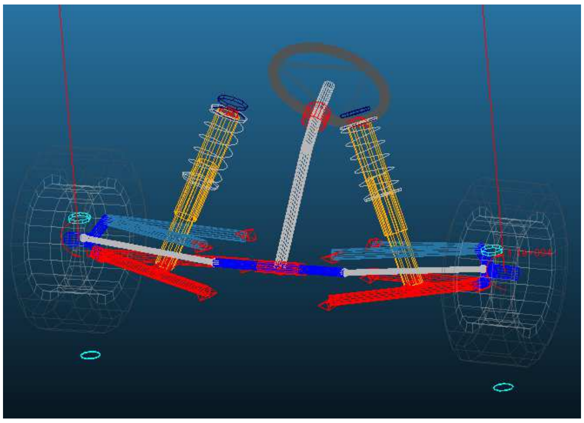


Figure 5: Suspension Wire Frame Model.

The simulation of (SLA) Double Wishbone was carried out according to above parameters and resultant graphs were plotted. The particular simulation was carried out under number of iteration until the obtained simulation value matches the required calculated value.

Hundred trails carried out over the parallel wheel travel of dual wishbone suspension. The values obtained under all the individual cycle of the suspension travel listed below with the parameter consideration

STATIC VALUES

CAMBER ANGLE	(deg):	0.00
TOE ANGLE (SAE) (+ve TOE IN)	(deg):	0.00
TOE ANGLE (PLANE OF WHEEL)	(deg):	0.00
CASTOR ANGLE	(deg):	-11.00
CASTOR TRAIL (HUB TRAIL)	(mm):	0.00
CASTOR OFFSET	(mm):	-56.78
KINGPIN ANGLE	(deg):	8.00
KINGPIN OFFSET (AT WHEEL)	(mm):	77.40
KINGPIN OFFSET (AT GROUND)	(mm):	36.34
MECHANICAL TRAIL	(mm):	-55.73
ROLL CENTRE HEIGHT	(mm):	288.75

GENERAL DATA VALUES

TYRE ROLLING RADIUS	(mm):	292.10
WHEELBASE	(mm):	1460.50
C OF G HEIGHT	(mm):	250.00
BREAKING ON FRONT AXLE	(%):	60.00
DRIVE ON FRONT AXLE	(%):	0.00
WEIGHT ON FRONT AXLE	(%):	40.00
OUTBOARD FRONT BRAKES:		
INDEPENDENT FRONT SUSPENSION:		
RACK TYPE STEERING ARTICULATION:		

RUN DETAILS

FRONT SUSPENSION ONLY:

BUMP TRAVEL	(mm):	166.50	INCREMENT	(mm):	10.00
REBOUND TRAVEL	(mm):	99.50	INCREMENT	(mm):	10.00
ROLL ANGLE	(deg):	3.00	ROLL INCREMENT	(deg):	0.50

Figure 6: Static Parameter Consideration.

INCREMENTAL SUSPENSION PARAMETER VALUES

BUMP TRAVEL (mm)	ANTI DIVE (%)	ANTI SQUAT (%)	ROLL CENTRE HEIGHT TO BODY (mm)	ROLL CENTRE HEIGHT TO GRND (mm)	HALF TRACK CHANGE (mm)	WHEELBASE CHANGE (mm)	DAMPER TRAVEL (mm)	SPRING TRAVEL (mm)
-100.00	46.05	0.00	368.22	468.22	-57.39	-18.22	48.90	48.90
-90.00	47.67	0.00	358.37	448.37	-50.09	-16.44	44.04	44.04
-80.00	49.36	0.00	349.08	429.08	-43.18	-14.66	39.18	39.18
-70.00	51.13	0.00	340.28	410.28	-36.65	-12.86	34.32	34.32
-60.00	52.98	0.00	331.93	391.93	-30.46	-11.05	29.45	29.45
-50.00	54.94	0.00	323.96	373.96	-24.62	-9.23	24.57	24.57
-40.00	57.01	0.00	316.35	356.35	-19.10	-7.40	19.68	19.68
-30.00	59.21	0.00	309.05	339.05	-13.89	-5.56	14.78	14.78
-20.00	61.56	0.00	302.03	322.03	-8.97	-3.72	9.87	9.87
-10.00	64.08	0.00	295.28	305.28	-4.35	-1.86	4.94	4.94
0.00	66.79	0.00	288.75	288.75	0.00	0.00	0.00	0.00
10.00	69.71	0.00	282.44	272.44	4.08	1.87	-4.96	-4.96
20.00	72.88	0.00	276.33	256.33	7.89	3.74	-9.94	-9.94
30.00	76.32	0.00	270.39	240.39	11.45	5.63	-14.95	-14.95
40.00	80.08	0.00	264.61	224.61	14.75	7.51	-19.97	-19.97
50.00	84.21	0.00	258.99	208.99	17.82	9.41	-25.03	-25.03
60.00	88.77	0.00	253.50	193.50	20.64	11.30	-30.10	-30.10
70.00	93.82	0.00	248.14	178.14	23.24	13.21	-35.21	-35.21
80.00	99.46	0.00	242.90	162.90	25.60	15.12	-40.34	-40.34
90.00	105.80	0.00	237.76	147.76	27.73	17.03	-45.50	-45.50
100.00	112.98	0.00	232.73	132.73	29.65	18.95	-50.69	-50.69
110.00	121.18	0.00	227.79	117.79	31.34	20.88	-55.92	-55.92
120.00	130.64	0.00	222.93	102.93	32.82	22.81	-61.18	-61.18
130.00	141.66	0.00	218.16	88.16	34.08	24.74	-66.48	-66.48
140.00	154.68	0.00	213.46	73.46	35.13	26.68	-71.82	-71.82
150.00	170.30	0.00	208.83	58.83	35.98	28.63	-77.19	-77.19
160.00	189.39	0.00	204.27	44.27	36.61	30.58	-82.61	-82.61
170.00	213.24	0.00	199.77	29.77	37.04	32.54	-88.07	-88.07

Figure 7: Dynamic Values Produced during Simulation.

FRONT SUSPENSION - ROLL
RHS WHEEL (+ve Y)

TYPE 1 Double Wishbone, damper to lower wishbone

INCREMENTAL GEOMETRY VALUES

ROLL ANGLE (deg)	CAMBER ANGLE (deg)	TOE ANGLE (deg)	CASTOR ANGLE (deg)	KINGPIN ANGLE (deg)	DAMPER RATIO [-]	SPRING RATIO [-]
-3.00	2.2751	-0.0336	-10.9290	5.7180	1.952	1.952
-2.50	1.8987	-0.0330	-10.9397	6.0946	1.962	1.962
-2.00	1.5211	-0.0305	-10.9509	6.4727	1.973	1.973
-1.50	1.1425	-0.0260	-10.9625	6.8523	1.984	1.984
-1.00	0.7627	-0.0195	-10.9745	7.2334	1.996	1.996
-0.50	0.3819	-0.0108	-10.9870	7.6160	2.007	2.007
0.00	0.0000	0.0000	-10.9999	8.0001	2.019	2.019
0.50	-0.3829	0.0131	-11.0133	8.3857	2.031	2.031
1.00	-0.7669	0.0285	-11.0272	8.7727	2.043	2.043
1.50	-1.1518	0.0463	-11.0416	9.1611	2.056	2.056
2.00	-1.5377	0.0665	-11.0564	9.5511	2.068	2.068
2.50	-1.9246	0.0894	-11.0718	9.9425	2.081	2.081
3.00	-2.3124	0.1150	-11.0876	10.3353	2.095	2.095

INCREMENTAL SUSPENSION PARAMETER VALUES

ROLL ANGLE (deg)	ROLL CENTRE POSITION X (mm)	Y (mm)	Z (mm)	HALF TRACK CHANGE (mm)	WHEELBASE CHANGE (mm)	DAMPER TRAVEL (mm)	SPRING TRAVEL (mm)
	(+ve Y to outer wheel:		Z rl to Grnd)				
-3.00	0.00	-54.53	287.43	-0.63	6.81	-18.09	-18.09
-2.50	0.00	-45.48	287.84	-0.44	5.66	-15.03	-15.03
-2.00	0.00	-36.41	288.17	-0.28	4.52	-11.99	-11.99
-1.50	0.00	-27.33	288.42	-0.16	3.38	-8.97	-8.97
-1.00	0.00	-18.23	288.61	-0.07	2.25	-5.96	-5.96
-0.50	0.00	-9.12	288.72	-0.02	1.12	-2.97	-2.97
0.00	0.00	0.00	288.75	0.00	0.00	0.00	0.00
0.50	0.00	9.12	288.72	-0.02	-1.11	2.96	2.96
1.00	0.00	18.23	288.61	-0.07	-2.22	5.89	5.89
1.50	0.00	27.33	288.42	-0.16	-3.31	8.81	8.81
2.00	0.00	36.41	288.17	-0.28	-4.40	11.71	11.71
2.50	0.00	45.48	287.84	-0.45	-5.47	14.60	14.60
3.00	0.00	54.53	287.43	-0.64	-6.54	17.46	17.46

Figure 8: Dynamic Values Produced during Suspension Roll.

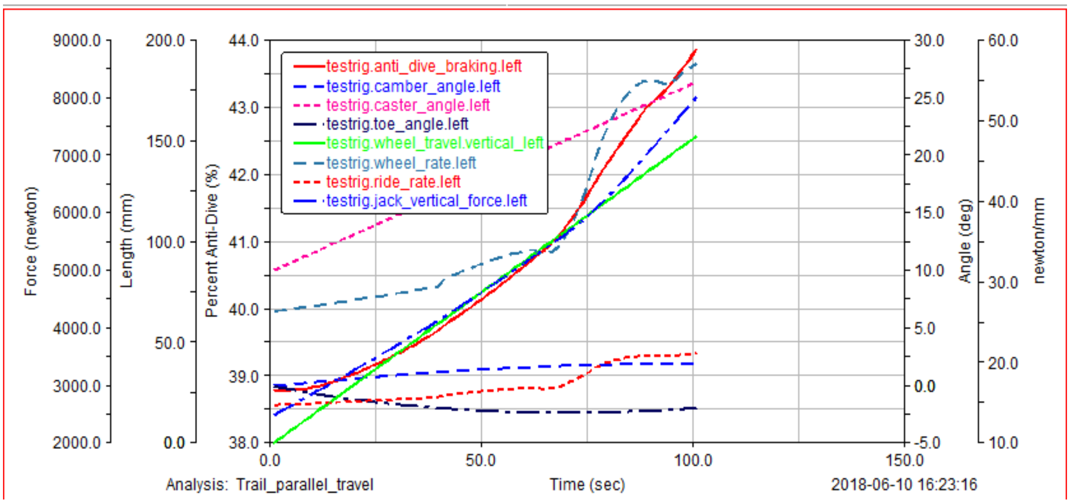


Figure 9: The Resultant Graph of all Performance Parameter in (SLA) Dual Wishbone Suspension Geometry.

5. CONCLUSIONS

The suspension geometry designed as per the required output with respect to all the performance parameter. The result obtained through simulation is closer to the values calculated. The suspension geometry designed for to maintain the good road contact in all terrain situation with minimum scrub radius and maximum wheel travel. The camber gain in drupe and rebound is minimum and so the caster and toe change. The suspension geometry designed to contribute higher vehicle stability with softer ride and good vehicle handling characteristics. The obtained results listed below in the table

Table 2: Results Obtained through Suspension Simulation

Parameters	Values	Units
Wheel Travel	152	mm
Roll Rate	8.5E + 005	N-mm/deg
Anti-Dive	30%	Percentage
Camber	1.75°	Degree
Caster	27°	Degree
Toe	-1.8°	Degree
Roll Centre	4.65	in
Jacking Force	6875	N
Scrub Radius	45	mm
King Pin Inclination	7.8°	Degree

The above results are obtained when the vehicle goes on six-inch drupe and two-inch pothole.

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